TECHNOLOGY
INTEGRATION
INCORPORATED

GEARBOX VIBRATION
DIAGNOSTIC ANALYZER
FINAL REPORT

Contract NAS3-26131

TII R9201-01-3RD

Submitted by:

Technology Integration, Incorporated
54 Middlesex Turnpike
Bedford, MA 01730

Submitted to:

National Aeronautics and Space Administration
Lewis Research Center
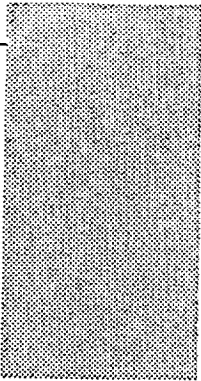Attn: Harry Decker, Bldg. 77, M.T. Stop 77-10
2100 Brookpark Road
Cleveland, OH 44135

54 Middlesex Turnpike • Bed

GEARBOX VIBRATION DIAGNOSTIC ANALYZER

FINAL REPORT

TECHNOLOGY INTEGRATION

54 MIDDLESEX TURNPIKE

BEDFORD, MA 01821

Contract NAS3-26134

I Table Of Contents

Section I

GEARBOX VIBRATION DIAGNOSTIC ANALYZER
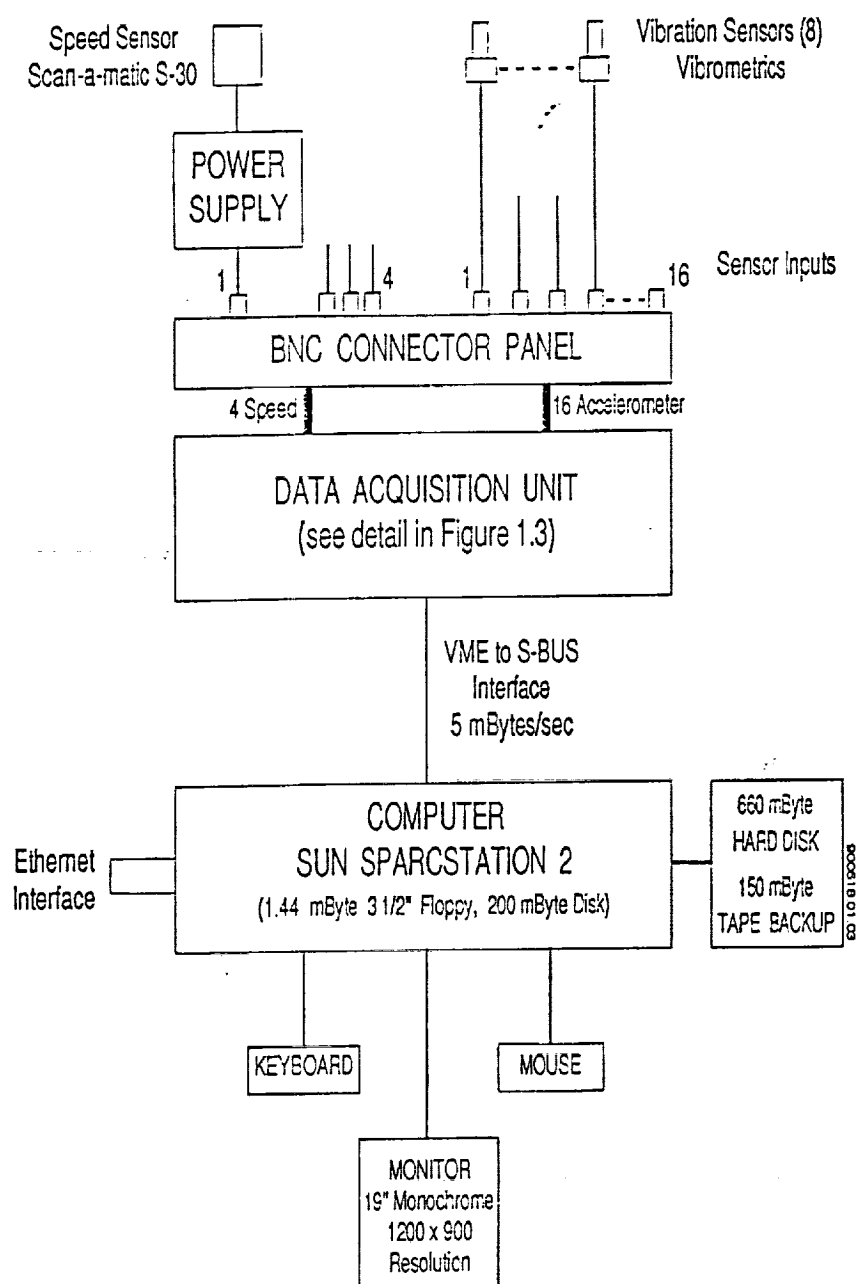
II *Introduction*

OverView of GVDA

The Gearbox Vibration Diagnostic Analyzer (GVDA) hardware design, shown in Figure 1.1, was designed expressly for the OH-58D main gearbox and incorporates expansion capabilities to accommodate additional sensor inputs. The system was delivered with 8 accelerometers and one speed sensor, which, based on our experience with the larger H-60 and H-53 gearboxes, is sufficient for vibration monitoring of the smaller OH-58D gearbox. The system was delivered with data input capability for up to 16 accelerometers, microphones, or tape channels and 4 speed sensors, providing the capability to add sensors without additional cost. In addition, the data acquisition unit has vacant slots available for additional 8 channel input boards and A/D boards. The data acquisition unit is connected to the computer by a high speed data bus link running at 5 MBytes per second.

The computer system is a Sun Microsystems SPARCStation 2, a 28 MIPS desktop computer with 1200 X 900 resolution monochrome monitor and 16 MBytes of memory. The hard disk provided has a storage capacity of 660 MBytes and a 150 MByte tape backup unit. The SPARCStation contains an internal 200 MByte disk which is used to store the operating system and its related files. The 660 MByte external disk is used for storing the IMADS software and all the setup, data, and analysis files generated during a test.

The anticipated operations with GVDA on the OH-58D teststand is primarily automatic, with all data available for later analysis. The automatic mode consists of data acquisition setups, diagnostic processing and reporting algorithms. These were entered during the system installation at NASA from a windowed interface by engineers. Programmers and knowledge of UNIX are not required. When a test is started, GVDA digitizes and processes data at user selected intervals. Text and graphic reports, including trend re-

Figure 1.1 Hardware Overview

Speed Sensor
Scan-a-matic S-30

Vibration Sensors (8)
Vibrometrics

POWER SUPPLY

1   4   1   16   Sensor Inputs

BNC CONNECTOR PANEL

4 Speed   16 Accelerometer

DATA ACQUISITION UNIT
(see detail in Figure 1.3)

VME to S-BUS
Interface
5 mBytes/sec

COMPUTER
SUN SPARCSTATION 2
(1.44 mByte 3 1/2" Floppy, 200 mByte Disk)

Ethernet
Interface

660 mByte
HARD DISK
150 mByte
TAPE BACKUP

KEYBOARD

MOUSE

MONITOR
19" Monochrome
1200 x 900
Resolution

ports, are output to the screen and printer during each test period. The outputs highlight any detected faults. The digitized data is stored on disk and tape for later analysis. The interval between acquisition periods is user controlled.

Detailed Description of Components

Sensors

ACCELEROMETERS

Eight high temperature, high frequency accelerometers with internal preamplifiers were provided. They are Vibrometer Model CE-677. This unit exceeds the specification, with a 400 F temperature capability, and a resonance frequency of about 60-kHz, which makes it useful for high frequency diagnostic analysis up to about 50-kHz. The accelerometers are designed to measure higher peak amplitudes than 100g, and because of the internal preamplifiers can drive long cables without noise interference problems.

The recommended mounting technique for the accelerometer is shown in Figure 1.2. This technique has been proven to provide satisfactory high frequency response.

SPEED SENSOR

The speed sensor is a SKAN-A-MATIC model S-30 infrared LED with a model T-41300 power supply and high speed amplifier. The sensor has a glass lens which keeps oil out of the sensor.

This speed sensor is used by Boeing Vertol for all its gearbox testing and has been evaluated to shaft speeds of up to 30,000 RPM. The speed sensor requires that a contrasting color strip be painted on the shaft. The paint does not need to be reflective, nor is reflective tape needed. The sensor's amplifier/power supply operates on 120V AC.

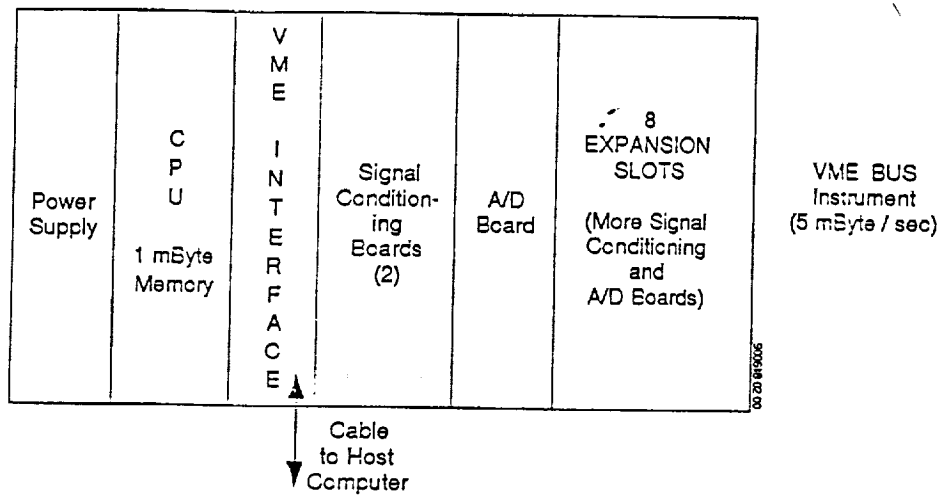## Figure 1.2 Sensor Installation Technique
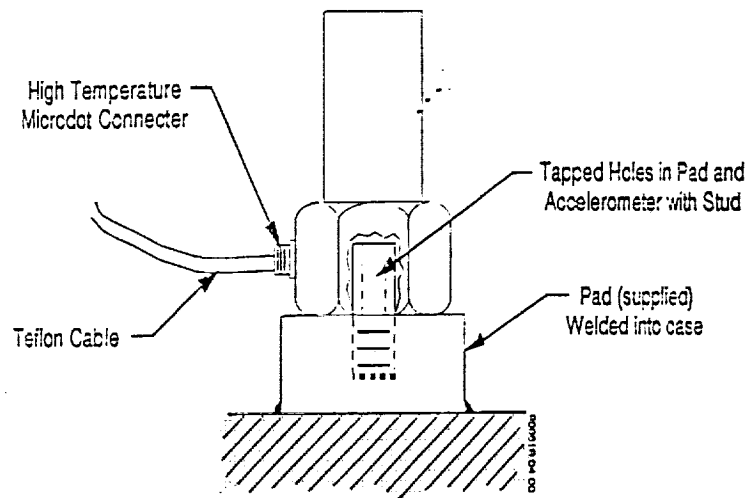
CABLES and TEST CELL HARDWARE

Teflon shielded microdot coax cable were used to connect the accelerometer outputs to a patch panel in the test cell. The speed sensor output is also connected to this patch panel.

A multiconductor coax connects the test cell patch panel to the GVDA connector interface panel. This cable runs through existing conduit, and was supplied and installed by NASA.
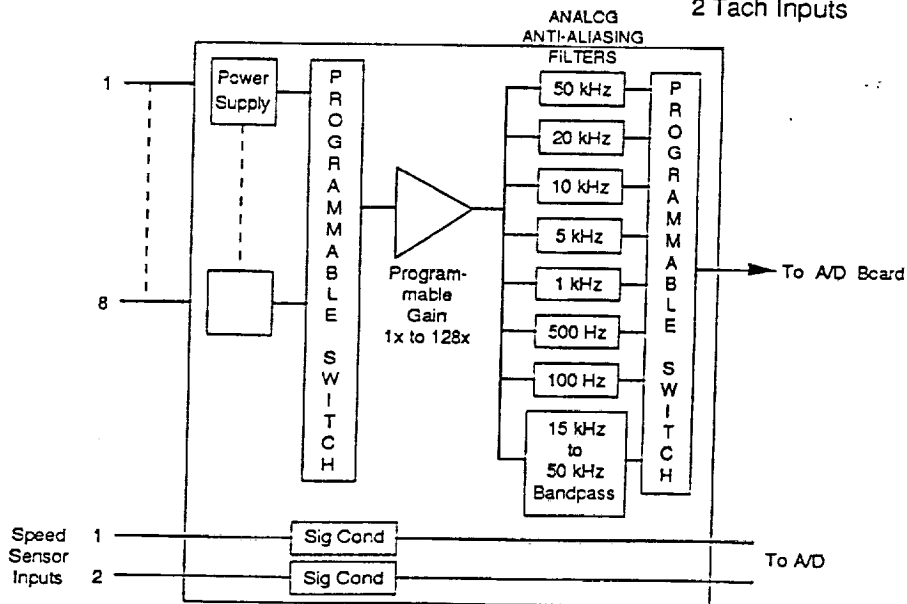
Signal Conditioning And Data Acquisition System

The signal conditioning and data acquisition system is shown in Figure 1.3. The unit has been specially designed for acquisition of digitized vibration data on machinery, and includes the capability to acquire speed and vibration sensor data simultaneously. The data acquisition unit consists of signal conditioning, A/D, host interface, and CPU boards. It is a rack mounted unit, based on the standard 6U VME bus. All boards except the signal conditioning board are third party commercial boards and are used without modification. The signal conditioning board, one of a family of computer controlled signal conditioning boards, is manufactured by TIDG and has been used in other real-time digital data acquisi-

Figure 1.3 Data Acquisition Unit

Power Supply	C P U 1 mByte Memory	V M E I N T E R F A C E	Signal Condition-ing Boards (2)	A/D Board	8 EXPANSION SLOTS (More Signal Conditioning and A/D Boards)

VME BUS Instrument (5 mByte / sec)

Cable to Host Computer

Signal Conditioning Board Detail - 8 Sensor Inputs
1 Sensor Output
2 Tach Inputs

ANALOG ANTI-ALIASING FILTERS

- 50 kHz
- 20 kHz
- 10 kHz
- 5 kHz
- 1 kHz
- 500 Hz
- 100 Hz
- 15 kHz to 50 kHz Bandpass

Power Supply

PROGRAMMABLE SWITCH

Program-mable Gain 1x to 128x

PROGRAMMABLE SWITCH

To A/D Board

Speed Sensor Inputs 1 — Sig Cond
2 — Sig Cond

To A/D

tion products; ROTABS, a helicopter rotor balancing unit, DETEQ, a helicopter sonar system, and in the IMADS system currently in production for the H-3 test cell at NADEP.

The unit was installed in available rack space in the test cell control room.

CONNECTOR INTERFACE PANEL

A panel with BNC inputs was provided for flexibility of sensor inputs. The output of the interface panel is wired directly to the signal conditioning board inputs. This panel provides the needed flexibility for analyzing tape recorded data or for installing sensors and testing other gearboxes than the OH-58D. The 16 accelerometer and 4 tachometer BNC inputs are available for any cable connection, and software was provided to setup the data acquisition unit for any sensor input scheme.

SIGNAL CONDITIONING BOARD

Figure 1.3 includes a detail of the signal conditioning board. This board provides for 8 accelerometer (or other sensor types) and for two tachometer inputs. The outputs of this board, two tachometer and one selected accelerometer output, are hard wired to the A/D board input.

Each accelerometer input includes a 15 V DC power supply. This is followed by a programmable switch for selecting one of the 8 channels for output, a programmable gain (1X to 128X), and a bank of eight selectable filters. The filter settings are shown in the figure, although these can be changed in the hardware if desired. Six of the filters are used for antialiasing. The seventh is a high frequency bandpass filter between 15 and 50 kHz. The output of this filter is used for high frequency processing diagnostics where substantial averaging is done on the data to improve signal to noise. A gearbox signal can have a large dynamic range in the frequency range from 1 to 50,000 Hz, in our experience over 70 dB is possible. This is beyond the limit of 12 bit A/Ds, so the only way to acquire data for high frequency signal to noise improvement is to filter out low frequency gearmesh levels. As a result, dynamic range is improved and signal averaging can provide a higher amount of fault signal to noise gain.

The signal conditioning board is programmed from the GVDA software. The user selects channel, gain, and filter setting for each of the signal conditioning boards for each acquisition. The acquisition setups are then stored and automatically run at user selected intervals or test condition. The A/D sample rate is automatically set from the filter setting.

A/D BOARD

A Data Translation Model 1492G -16SE is used for the A/D. This board, as shown in Figure 1.4, has 16 inputs and a programmable

Figure 1.4 A/D Board

Data Translation 1492
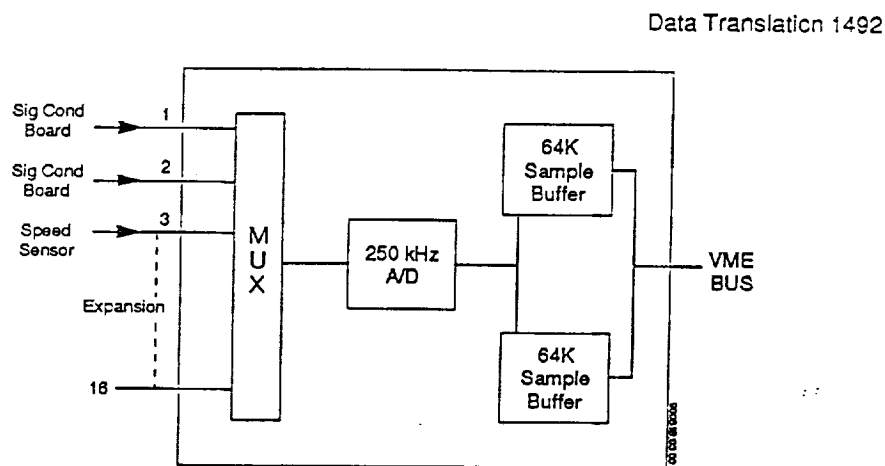
A. The Mux can sample any combination of inputs at any rate. Since the speed sensor will be sampled at about 5 kHz, we will be able to sample two simultaneous data channels at above 120 kHz per channel.

B. The two 64K sample buffers (called ping-pong buffers) allow for continuous sampling.

C. An optional 750 kHz, 4 channel input A/D is available.

MUX so that any combination of inputs and sampling order can be selected. The maximum rate of the A/D is 250-kHz, so two sensors

may be sampled at an upper sample rate limit of 120,000 samples per seconds, while the tachometer is sampled at 10,000 samples per second. This will provide the upper frequency limit of 50,000 Hz per sensor.

The A/D board has two 64 k sample buffers which are programmed to work in a ping-pong fashion when long continuous samples are needed. The CPU transfers the contents of one buffer to its memory space while the other is being filled. The A/D board is setup from the GVDA software, by selecting the length of the sample, and the gain. All other settings are automatic.

DATA INTERFACE TO HOST

A Bit-3 Computer VME to S-Bus interface board set and cable, Model 466, were provided to connect the data acquisition unit to the Sun host computer.

CPU

The data acquisition unit uses a Motorola CPU with a 68020 processor.

Computer-based Controller And Signal Processing System

The computer is a Sun Microsystems SPARCStation 2 desktop workstation. This computer operates under UNIX, a multitasking operating system that provides the capability to collect, process and analyze data all at the same time. The computer features 28 MIPS processing speed, a 32 bit bus with 3 internal slots, 16 MBytes memory, an internal 200 MByte disk, a mouse, keyboard, 3 1/2 inch floppy disk (1.44 MBytes), and Ethernet interface, and a monochrome monitor.

Display System

The computer is provided with a 19" high resolution (1200 X 900) monochrome monitor.

Hard-copy Output Device

A Sun SPARCPrinter laser postscript printer is attached to an S-Bus slot. The printer has 12 page per minute speed and 400 dots per inch resolution.

Data Storage System

Two external data storage devices were supplied, a 660 MByte hard disk, and a 150 MByte tape backup unit. These devices were located in a single peripheral unit about the size of a shoe box. They are connected to the computer by a SCSI interface. The computer also contains a 200 MByte internal disk which is used to hold programs and the operating system.

The internal 3 1/2 inch floppy disk can be used to transfer data files to PC computers. The Sun operating system supports reading and writing to floppy disks in DOS format.

III Overview of IMADS 1+

Details of the software are in the manuals delivered with the system, and will not be repeated here, since they are largely proprietary design data.

In summary, IMADS was supplied with all the digital signal processing functions necessary to implement user defined diagnostic algorithms. These DSP tools were used in TII's proprietary diagnostic algorithms supplied with the system. The following paragraphs summarize the algorithms supplied with the system.

Shaft Imbalance

Shaft imbalance is detected by determining the ratio of the power at the shaft fundamental frequency to the total power in the first three harmonics of the shaft fundamental frequency. Time synchronous averaged data is used to increase the signal to noise at these frequencies and the actual processing is done using order analysis. This technique has been tested and used by several different researchers.

Shaft Misalignment

See gear misalignment because if a gear is misaligned, the shaft will be misaligned as well.

Gear Misalignment

GVDA gear misalignment techniques were developed from gear vibration models based on research done by W. Mark at Bolt, Beranek and Newman, including some work funded by NASA Lewis. The analysis showed that ratios of levels at various gearmesh harmonics as a function of load would indicate mis-

alignment. We currently use three functions, shown in the tool box as mis1, mis2 and mis3. Mis1 and mis2 compare the level at the first and second gear mesh harmonic to the level at the fundamental respectively. They can be used on both spur and spiral bevel gears. mis3 is for spur gears only, and compares the level at the first harmonic at a high torque setting to the level at a low torque setting. The thresholds were derived from the model results.

These techniques have proven to be successful at NADEP in detecting misaligned gears. We are continuing to work on selecting the most meaningful values of the thresholds. Time synchronous averaged data and order analysis are used in the processing.

Gear Tooth Faults

The basic methods are used to detect gear faults such as cracks, wear, and tooth loss are envelope analysis, and Hilbert envelop analysis. These methods combine methods that are considered separate by other researchers. Other methods are currently under development or are being investigated as part of our Navy research. Other methods can also be input using the diagnostic algorithm toolbox.

The methods require time synchronous averaging unless there is a high level of signal to noise at the gear mesh frequency.

In envelope analysis, the data are filtered through a high frequency bandpass filter, averaged, demodulated and then the spectrum is calculated. This method was illustrated in a previous section, the only difference being that for gears, the averaging can be done in the time domain with a resulting improvement of fault signal to noise ratio. The kurtosis and / or sixth moment is calculated in the time domain and gearmesh frequency amplitude is measured in the frequency domain.

The Hilbert envelope analysis is based on work done at the Australian Research Laboratory. The time data are bandpass filtered about the gearmesh fundamental, time synchronous averaged, and then the Hilbert envelope is calculated. A tooth crack will result in an unloading at mesh which will show up as a drop out in the amplitude envelope and a sudden phase change in the phase. The kurtosis of the amplitude and phase are calculated to automatically detect the changes. In addition, the power spectrum of the amplitude envelope is calculated, and levels at harmonics of

shaft rate measured. This indicated modulation not caused by a single tooth fault, but by imbalance or misalignment since the modulation occurs throughout the gear rotation.

Other types of analyses can be performed on the data using the toolbox of signal processing routines, but they have not been implemented at NADEP because they do not lend themselves to automatic detection with a low false alarm rate. Examples of this are computing the relative levels at the sideband frequencies of gearmesh, either through reading levels directly from a power spectrum or using Cepstrum analysis. Processing for these analyses can be easily implemented in GVDA for manual study of the output plots.

Spalling and Pitting of Races and Balls

The envelope analysis previously discussed is used for this. We have had very good success detecting very early faults including microscopic pits with this technique. When combined with time trending this technique will result in a time to failure prognostic capability. We will be starting an SBIR research contract for the Army in Fall 1990 to investigate time to failure prognostic algorithms for helicopter gearboxes.

We have found that sensor location and filtering range are highly critical in successful bearing fault detection, so work specific to the OH-58D will need to be done during the installation phase of the project.

Our ongoing work for NASA Marshall on bearing fault detection has shown that tracking cage frequency levels can indicate faults in the roller. The advantage of using cage frequency is that it is directly proportional to shaft frequency and slip is not a problem. Thus synchronous averaging can be used to improve signal to noise ratios.

Excessive Bearing Wear

The envelope method has detected bearings beyond the multiple pit stage, including a bearing where the race was completely scored about its circumference. This is likely because the impacts are only generated in the bearing load zone so they still appear discrete in time.

Severely worn bearings are usually detected by an increase in broadband level. One of our tests is the broadband amplitude, but it has not been effective at NADEP because there is no time trend data.

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1992	Final Contractor Report

4. TITLE AND SUBTITLE

Gearbox Vibration Diagnostic Analyzer, Final Report

5. FUNDING NUMBERS

WU–505–63–36
C–NAS3–26134

6. AUTHOR(S)

Technology Integration, Inc.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Technology Integration, Inc.
54 Middlesex Turnpike
Bedford, Massachusetts 01730

8. PERFORMING ORGANIZATION REPORT NUMBER

E–9589

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135–3191

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CR–189141
R9201–001–RD

11. SUPPLEMENTARY NOTES

Project Manager, Harry J. Decker, Propulsion Systems Division, NASA Lewis Research Center, organization code 2730 (216) 433–3964.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 00

This publication is available from the NASA Center for Aerospace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report describes the Gearbox Vibration Diagnostic Analyzer installed in the NASA Lewis Research Center's 500 HP Helicopter Transmission Test Stand to monitor gearbox testing. The vibration of the gearbox is analyzed using diagnostic algorithms to calculate a parameter indicating damaged components.

14. SUBJECT TERMS

15. NUMBER OF PAGES

19

16. PRICE CODE

A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

National Aeronautics and
Space Administration

Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135-3191